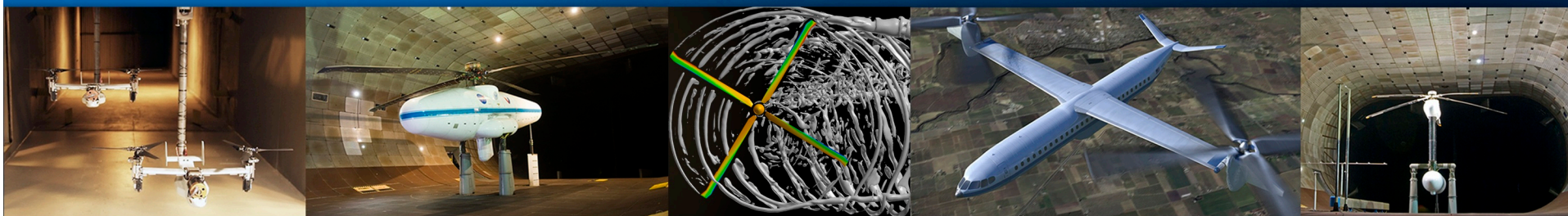




Effects of Fuselage and Wind Tunnel Modeling on Airloads and Performance Predictions

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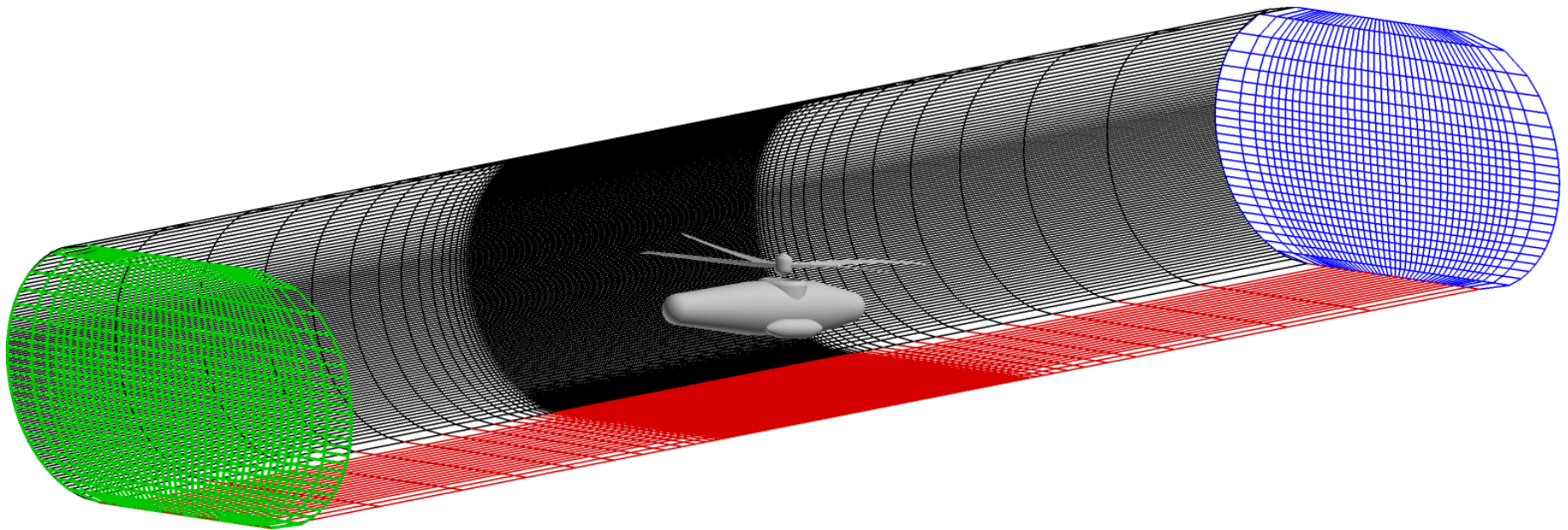
Objective/Approach

- Objective
 - Investigate effects of fuselage and wind tunnel modeling on airloads and performance predictions
- Approach
 - Use coupled OVERFLOW/CAMRAD code to predict airloads and performance for speed and thrust sweep conditions
 - Compare with measured data from UH-60A Airloads wind tunnel test



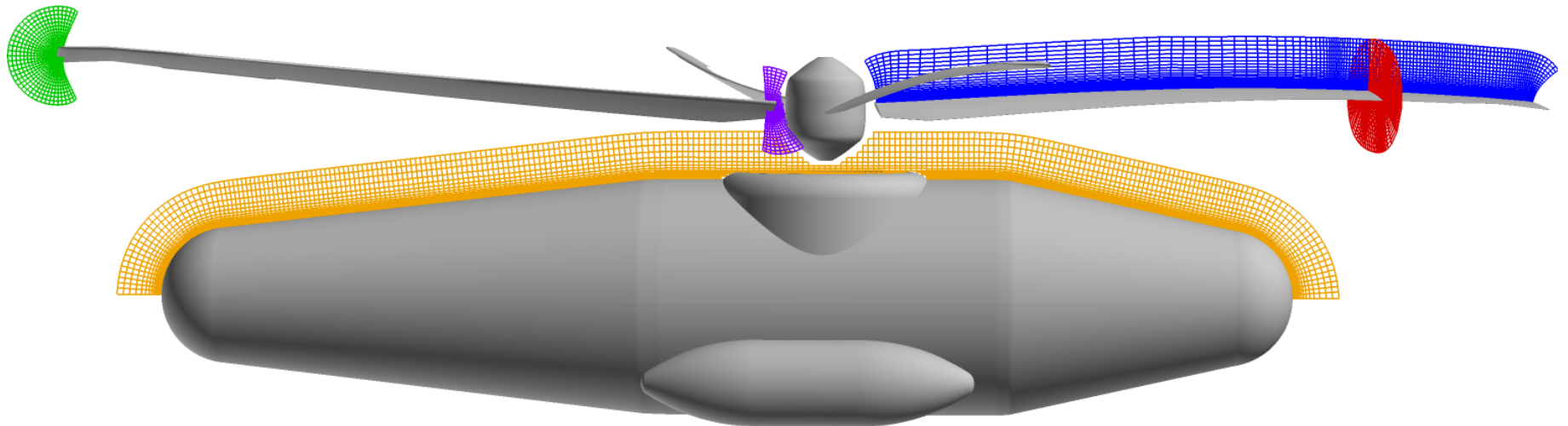
CFD Grid Modeling

- Computational grid system of UH-60A rotor mounted on the LRTA test stand in the 40- by 80-Foot Wind Tunnel generated by OVERGRID
- Grid system consists of 31 grids with more than 38.3 million mesh points



CFD Grid Modeling (near-body grids)

- Fifteen near-body grids used to model the rotor
 - 12 grids described the UH-60A rotor, with 3 grids (blade, root cap and tip cap) for each of four blades
 - 3 grids defined an artificial hub (hub, top cap and bottom cap).
- Eight near-body grids used to model the LRTA
 - LRTA grids could be added or removed from simulation without altering the rotor grids

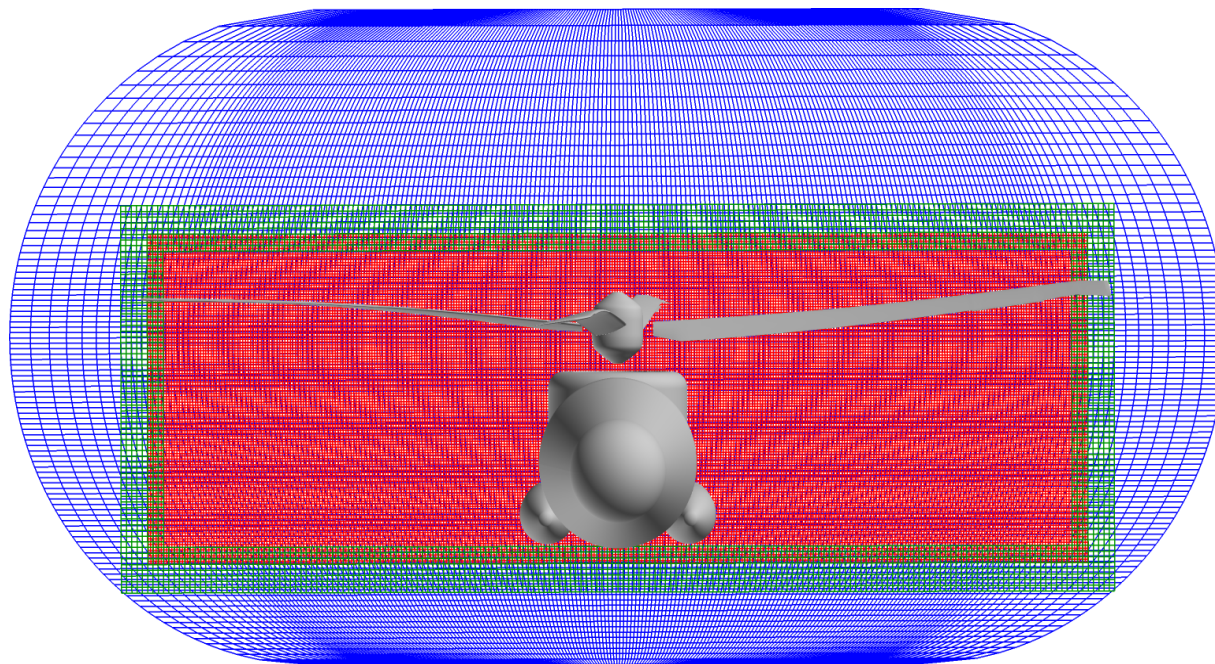


CFD Grid Modeling (off-body grids) – Free Air

- Free-air simulation consists of near-body grids and an off-body grid set composed of uniform Cartesian blocks
 - Off-body grids arranged in shells around rotor - denoted as level 1 to 5.
- Level 1 grid was single block, slightly larger than rotor disk and extending slightly above and several chords lengths below
 - Spacing in this block was 10% of rotor chord length constant in all three directions
- Each successive layer enclosed the former and had twice the spacing of preceding layer
- Far edges of level 5 grid were five rotor radii (26.8333 ft) from hub

CFD Grid Modeling (wind tunnel grids)

- 40- by 80- Foot Wind Tunnel modeled as a straight tunnel section
 - 247.6 feet long with cross section dimensions same as test section
 - Rotor hub center located at center of cross section 123.9 feet down-stream from the wind-tunnel entrance plane
- Grid has mesh-point dimensions of 208x206x99 (stream-wise, lateral, vertical) clustered near rotor
- Level 1 and level 2 grids from free-air simulation were extracted and used to convert the flow between the rotor and tunnel grids



Results

- Predictions were made for three different CFD configurations:
 - a) rotor only (in free air with Glauert-type shaft angle correction)
 - b) rotor inside wind tunnel
 - c) rotor and LRTA inside wind tunnel
- Predictions of sectional airloads and rotor performance are compared with NFAC test data for
 - a) the speed sweep (Run 52)
 - b) the thrust sweep (Run 45)

Speed Sweep (Run 52)

- Speed sweep conditions ($\mu = 0.15$ to 0.40) acquired at constant thrust/lift ($C_T/\sigma = 0.09$) and hover tip Mach number ($M_{tip} = 0.65$)

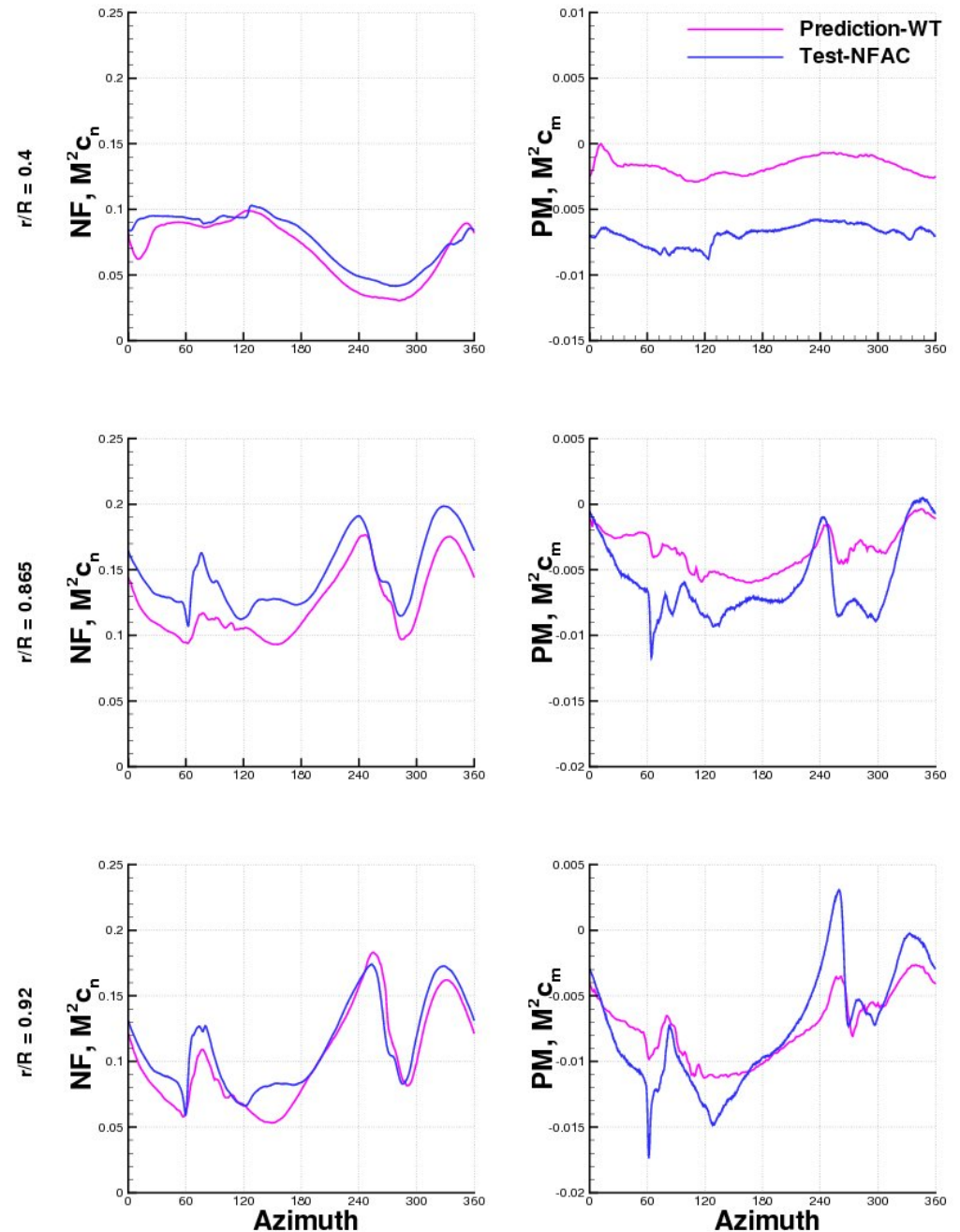
Point	M_{tip}	μ	C_T/σ	α_s (deg)	α_c (deg)
15	0.65	0.15	0.09	-1.9	0.9
20	0.65	0.2	0.09	-1.9	-0.3
30	0.65	0.3	0.09	-4.2	-3.49
41	0.65	0.37	0.09	-7.2	-6.74
51	0.65	0.4	0.09	-8.0	-7.6

- Airloads comparisons will be presented for low and high speed cases
- Performance comparisons will be made for all five cases

Run 52 Point 15

$M_{tip} = 0.65$, $\mu = 0.15$, $\alpha_s = -1.9^\circ$, $\Delta\alpha = 0.0^\circ$, $C_t/\sigma = 0.09$

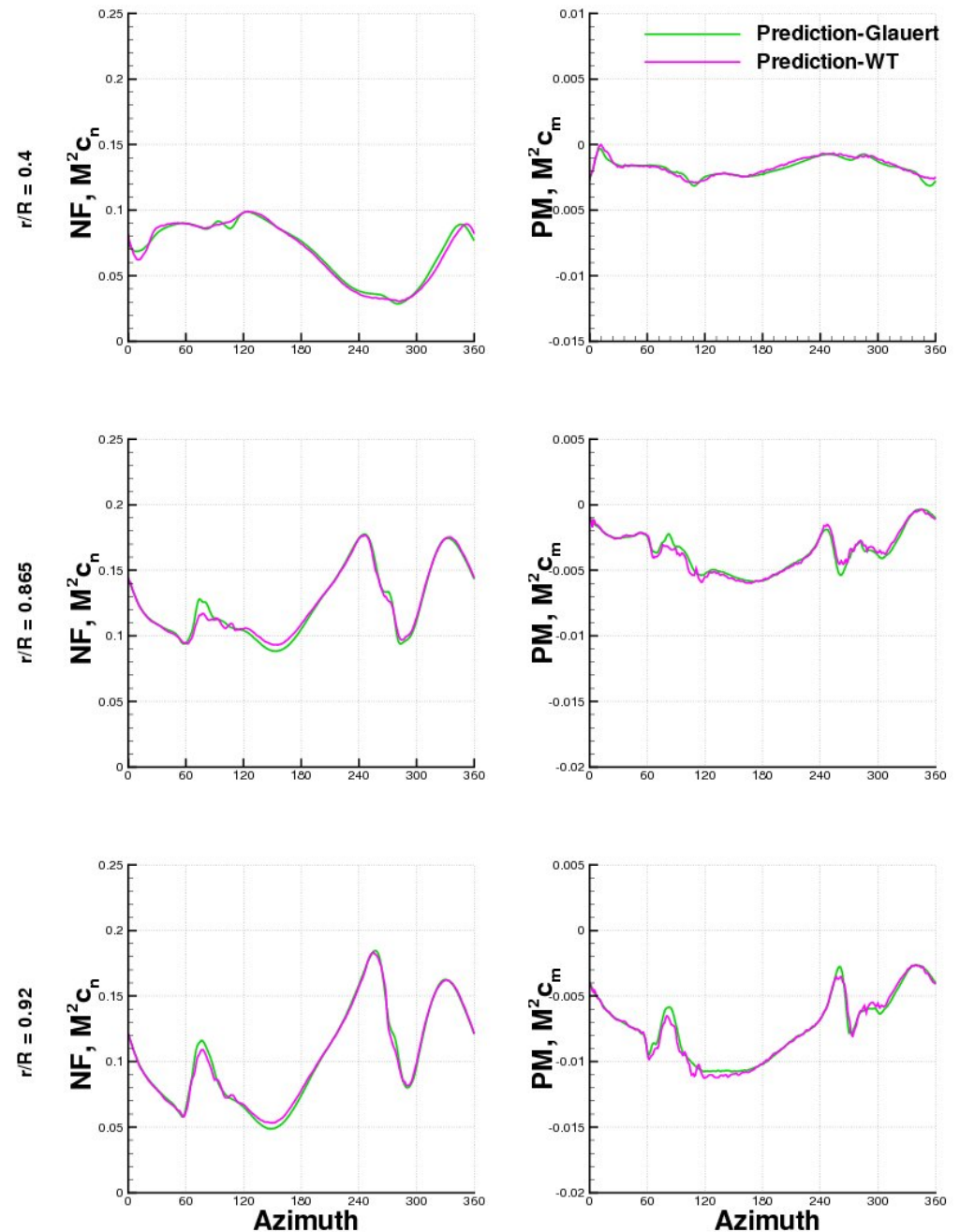
- NF and PM from rotor/WT prediction and test data – low speed case
- Reasonable NF predictions
- PM distributions not as well captured, with some variations in steady values as well as the high frequency events
- Results provide confidence that extension of coupled OVERFLOW/CAMRAD code from free-air to wind tunnel environment was successful



Run 52 Point 15

$M_{tip} = 0.65$, $\mu = 0.15$, $\alpha_s = -1.9^\circ$, $\Delta\alpha = 2.8^\circ$, $C_t/\sigma = 0.09$

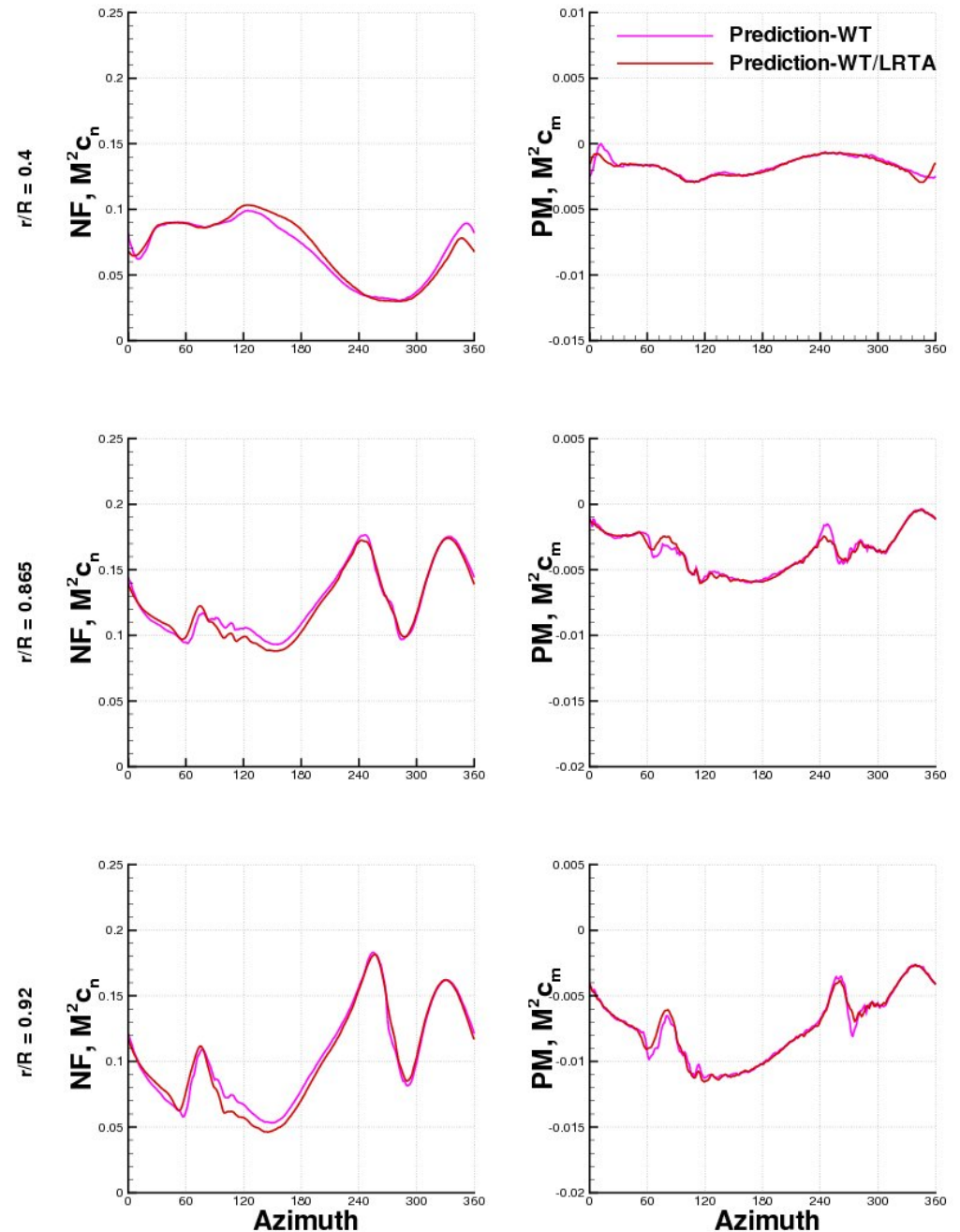
- NF and PM from rotor/WT and rotor-only predictions
- Rotor-only computations used Glauert-corrected shaft angle as a priori input (to account for upwash effects of tunnel walls). Shaft angle correction for this case was 2.8 deg.
- Comparisons suggest Glauert correction appears to work well for this low-speed test condition



Run 52 Point 15

$M_{tip} = 0.65$, $\mu = 0.15$, $\alpha_s = -1.9^\circ$, $\Delta\alpha = 0.0^\circ$, $C_t/\sigma = 0.09$

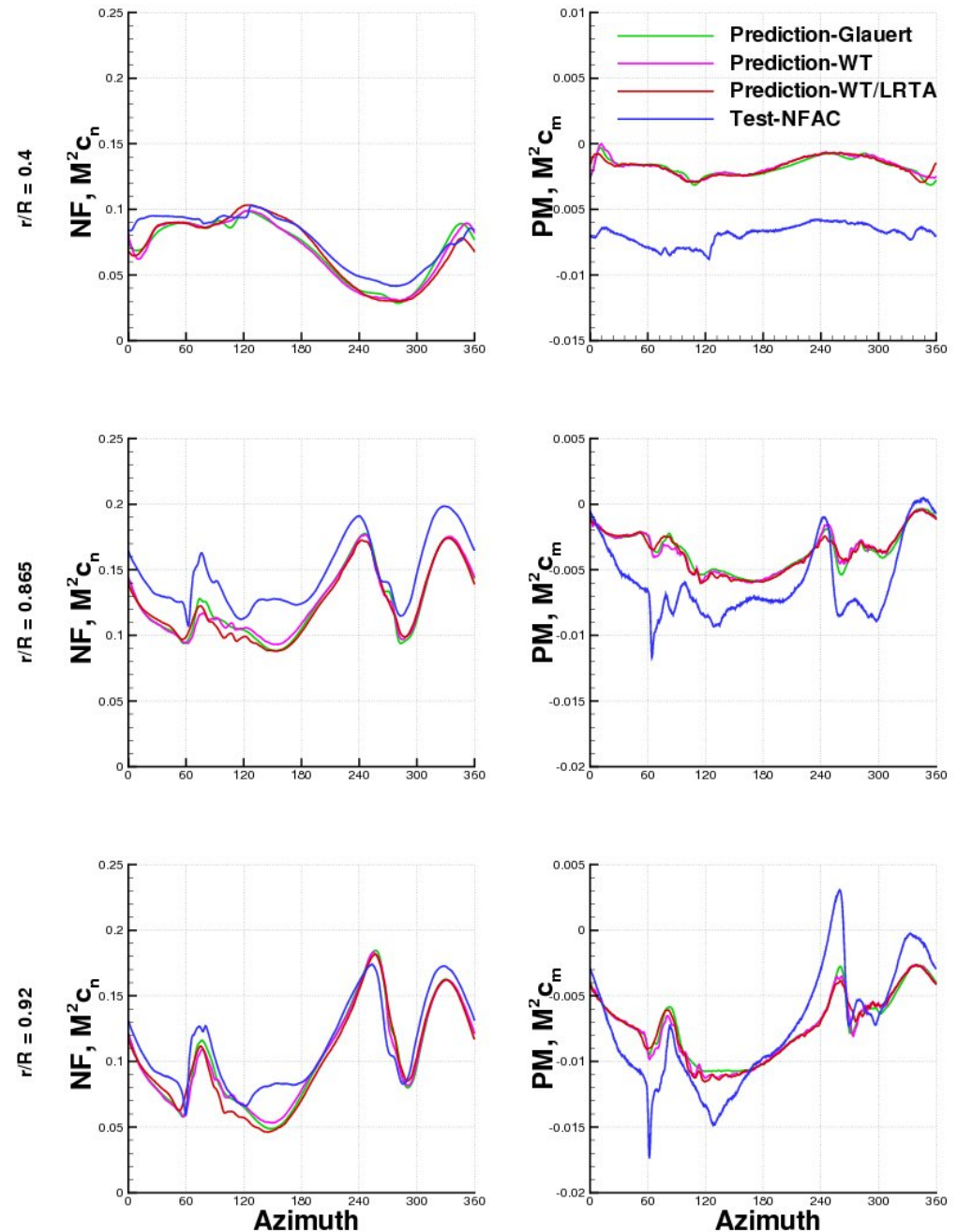
- NF and PM from rotor/WT and rotor/WT/LRTA predictions
- Small but noticeable differences in NF on advancing side at outboard stations and over the nose and tail at inboard station
- Very little difference in PM
- In general, the effects of the LRTA on airloads is small at this low-speed test condition.



Run 52 Point 15

$M_{tip} = 0.65$, $\mu = 0.15$, $\alpha_s = -1.9^\circ$, $\Delta\alpha = 2.8^\circ$, $C_t/\sigma = 0.09$

- **NF and PM from test data and predictions (rotor-only, rotor/WT and rotor/WT/LRTA)**
- Standard figure for remaining comparisons
- For this low-speed case, modeling of wind tunnel and LRTA have only a small effect on predicted airloads
- Blade vortex interaction (BVI) events on advancing side underpredicted

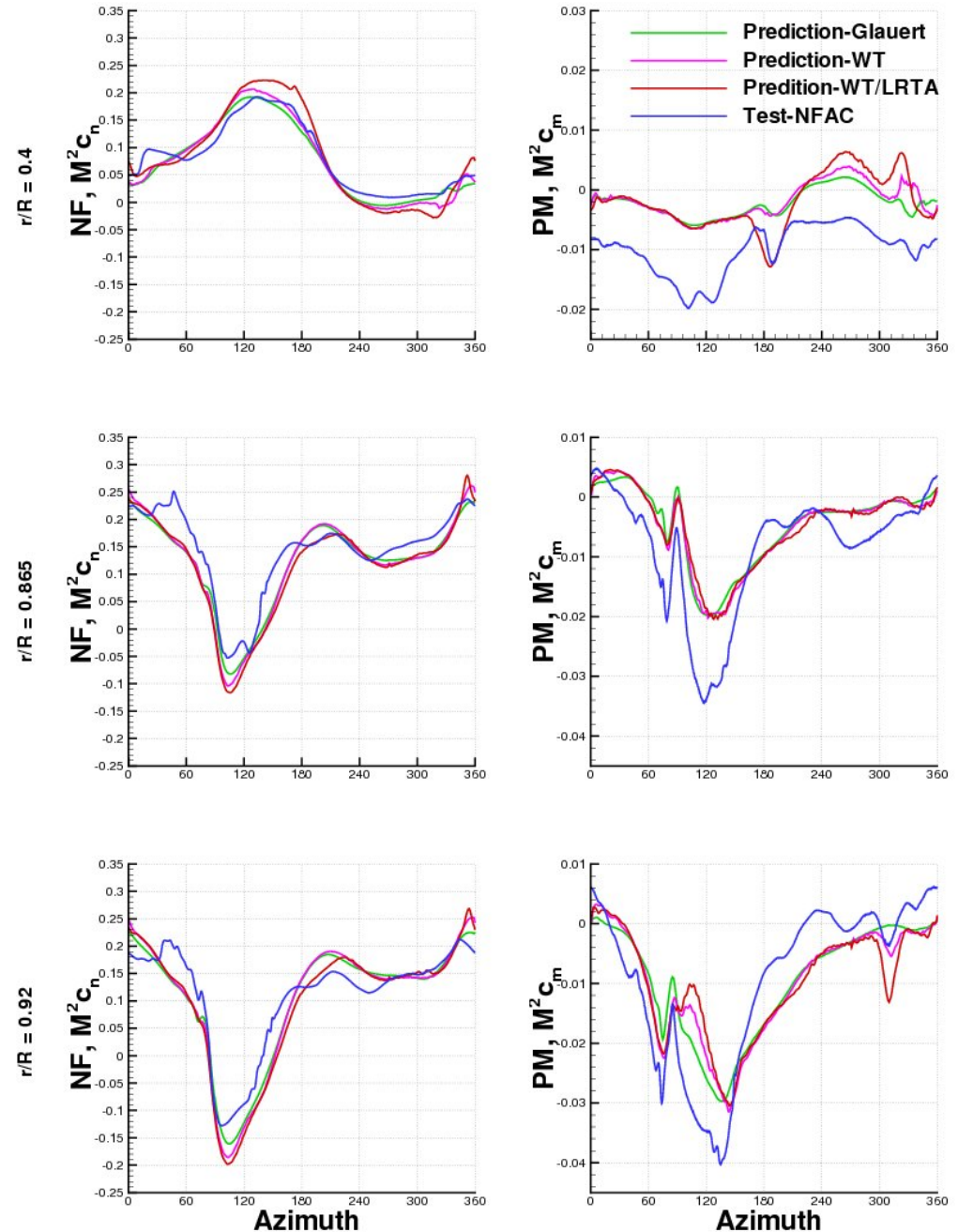


- **NF and PM for high speed case**

- Larger differences between the rotor-only and rotor/WT predictions. Differences suggest Glauert correction may not be adequate at this condition
- Noticeable NF and PM differences between rotor/WT and rotor/WT/LRTA on advancing side. Additional differences in PM on retreating side
- With transonic shock events on advancing side over-predicted.
- Analysis at other advance ratios suggests WT modeling is important at advance ratios greater than $\mu = 0.37$ and LRTA modeling becomes increasingly important as advance ratio increases
- All predictions still show significant differences with test data

Run 52 Point 51

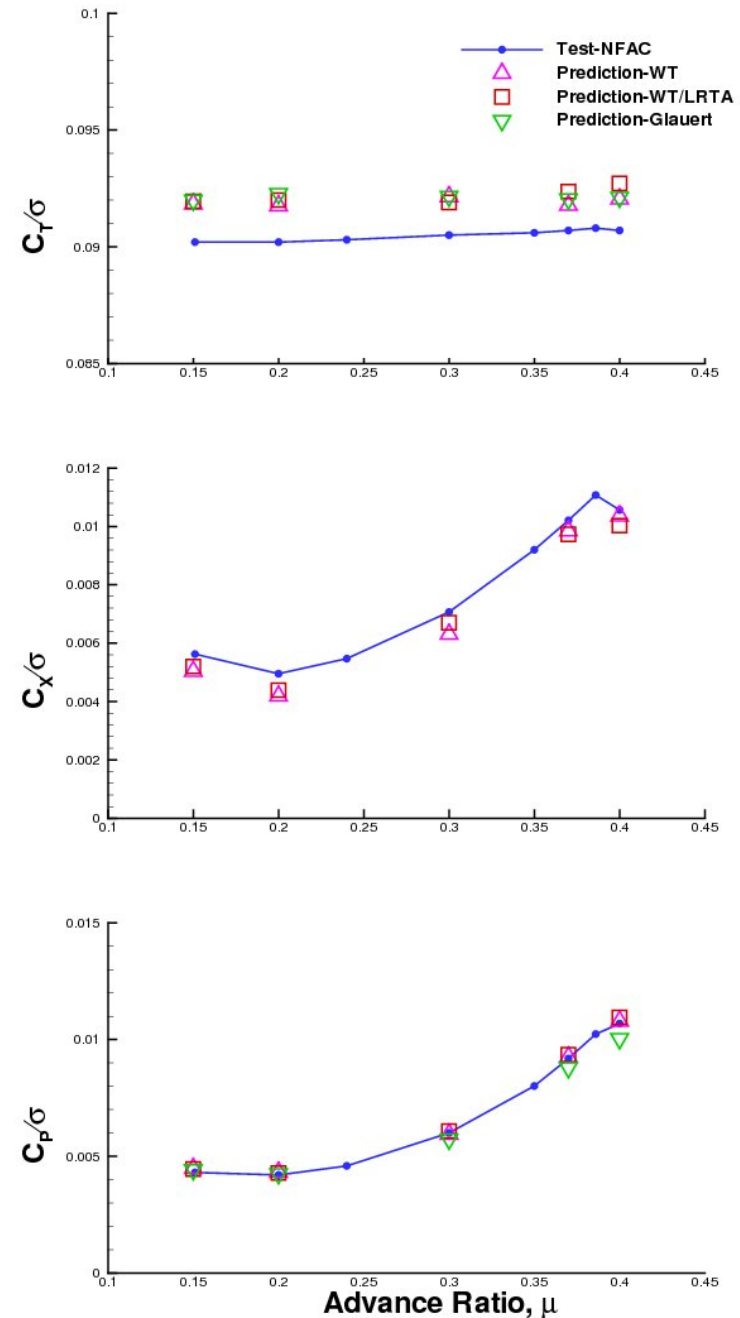
$M_{tip} = 0.65$, $\mu = 0.4$, $\alpha_s = -8.0^\circ$, $\Delta\alpha = 0.395^\circ$, $C_f/\sigma = 0.09$



Performance Results for Speed Sweep

- Rotor thrust computed from OVERFLOW was nominally 2.5 % higher than measured values for all advance ratios (attributed to force conservation issues between CAMRAD and OVERFLOW)
- Propulsive force is slightly under predicted for both two direct wind tunnel modelings at all speeds (prediction-Glauert is not available for this plot set-up)
- Power is well predicted for both direct wind tunnel modelings for all speeds and is slightly under prediction for Glauert for high speed region.

Run 52 Series
OVERFLOW2 Performance Results



Thrust Sweep (Run 45)

- Thrust sweep conditions ($C_T/\sigma = 0.02$ to 0.1255) acquired at constant advance ratio ($\mu = 0.3$), hover tip Mach number ($M_{tip} = 0.625$) and geometric shaft angle ($\alpha_s = 0^\circ$)

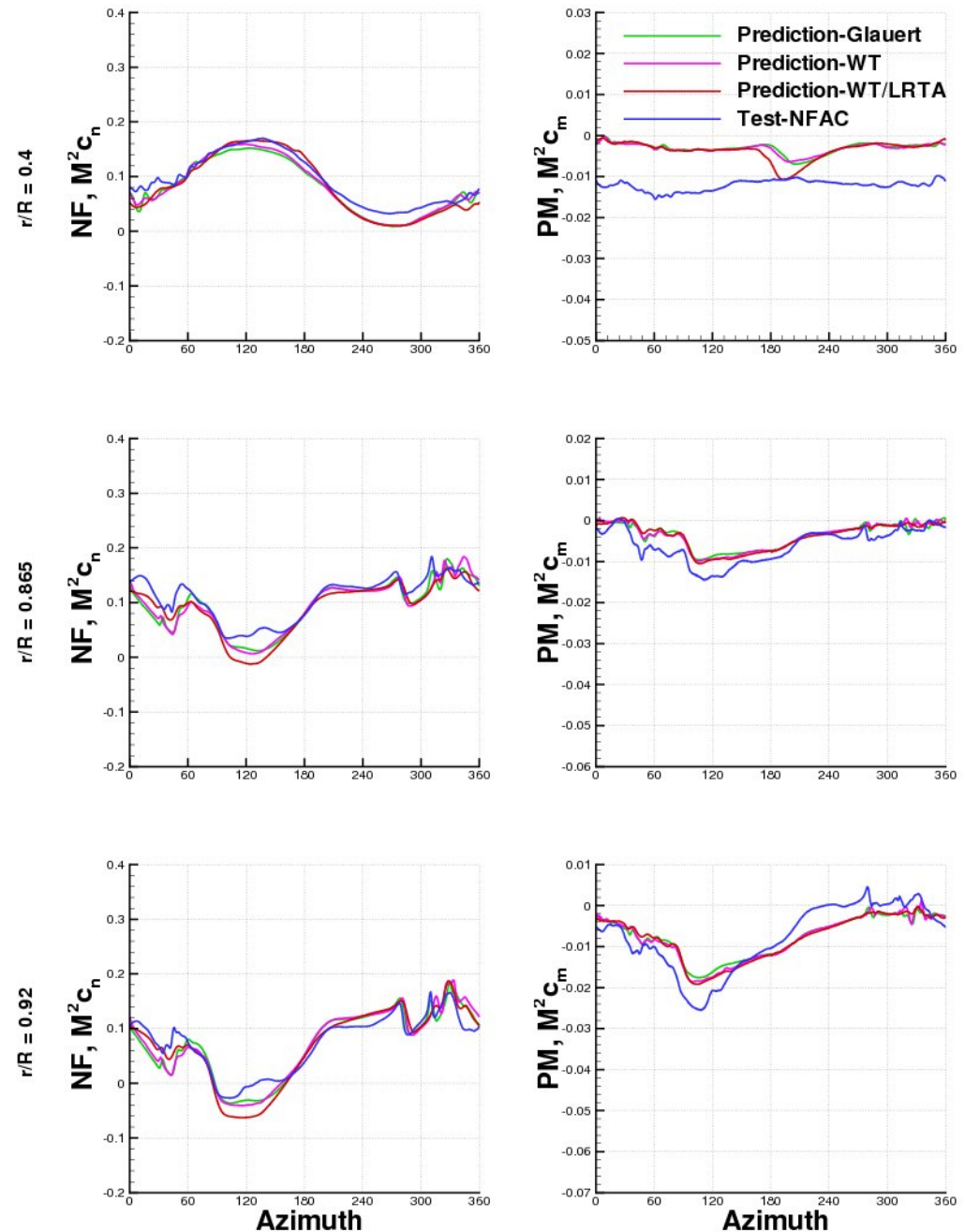
Point	Mtip	μ	C_T/σ	α_s (deg)	α_c (deg)
30	0.625	0.3	0.06	0.0	0.47
32	0.625	0.3	0.08	0.0	0.63
33	0.625	0.3	0.09	0.0	0.70
35	0.625	0.3	0.1104	0.0	0.86
37	0.625	0.3	0.1253	0.0	0.98
38	0.625	0.3	0.1255	0.0	0.98

- Airload comparisons will be presented for moderate and high thrust cases.
- Performance comparisons will be made for all six cases

Run 45 Point 33

$M_{tip} = 0.625$, $\mu = 0.3$, $\alpha_s = 0.0^\circ$, $\Delta\alpha = 0.70^\circ$, $C_t/\sigma = 0.0901$

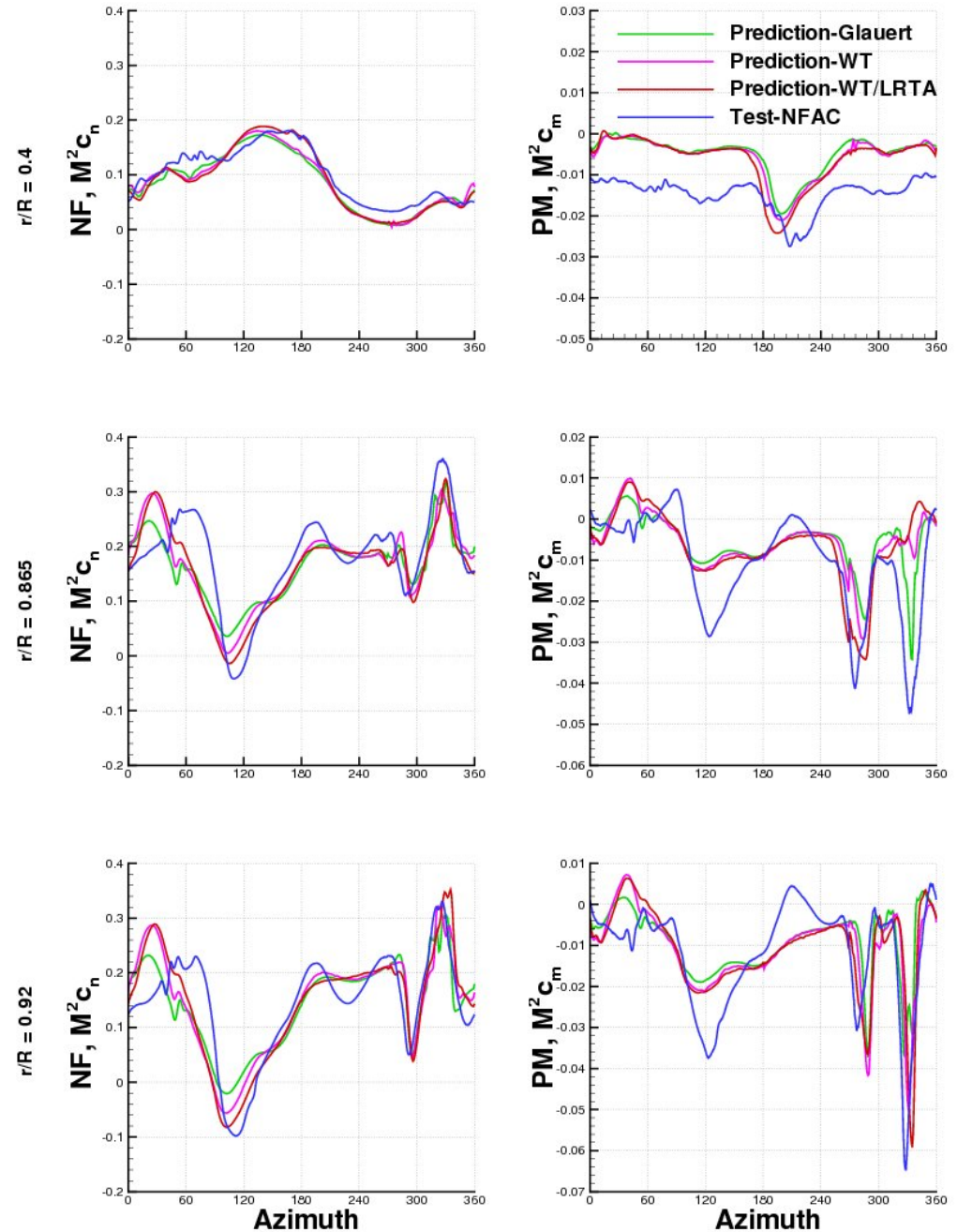
- **NF and PM for moderate thrust case**
- Comparisons of rotor/WT and rotor-only predictions show few differences. Glauert shaft angle corrections provide good results at this conditions.
- Effects of LRTA modeling on airload predictions are consistent with previous results. Primary difference seen in pitching moment is dip near 200 deg at $r/R = 0.4$.
- Overall correlation of the three simulation results with NFAC test data is generally good



Run 45 Point 38

$$M_{tip} = 0.625, \mu = 0.3, \alpha_s = 0.0^\circ, \Delta\alpha = 0.98^\circ, C_t/\sigma = 0.1255$$

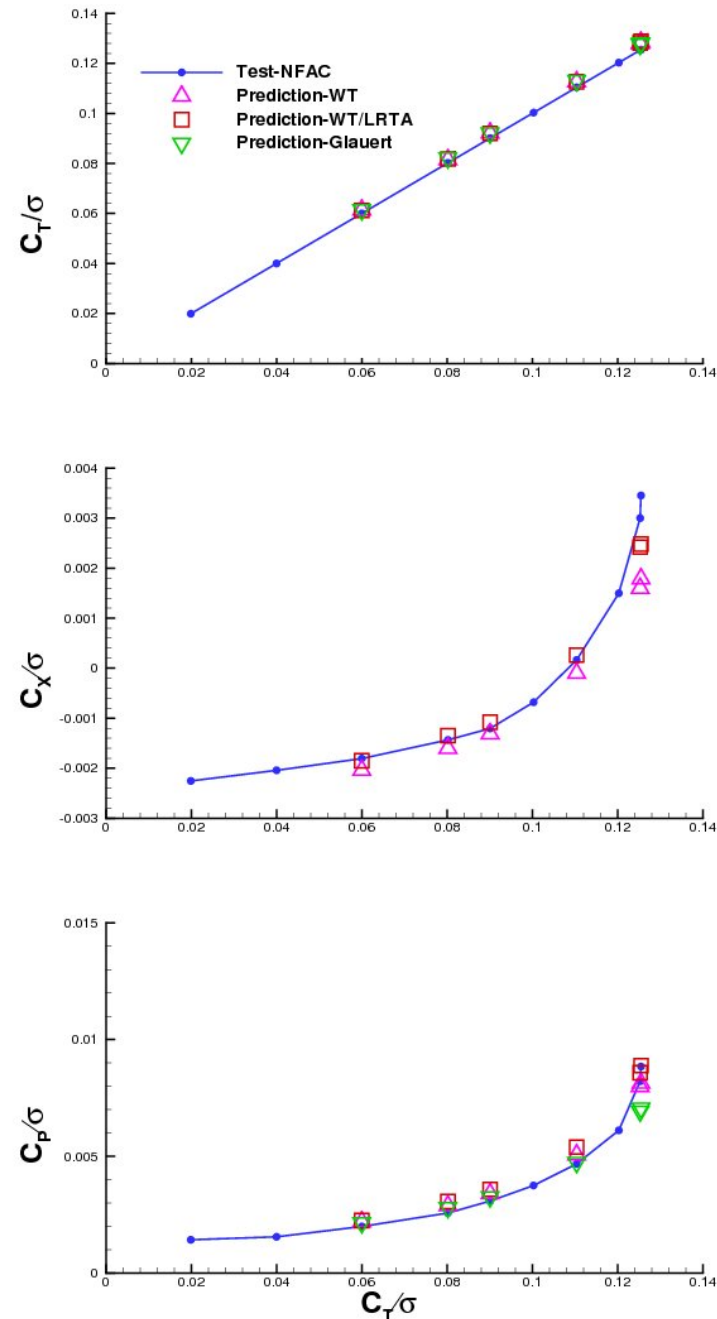
- **NF and PM for high thrust case**
- Modeling of WT and LRTA have larger effect at this condition. Most apparent for NF on advancing side and PM on retreating side
- Noticeable differences near 120 deg (shock) and 300 deg (stall) suggest 3-D wind tunnel effects are missed by Glauert correction
- LRTA modeling provides best correlation with data
- Negative PM trough near 150 deg missed
- Analysis at other thrust levels suggests WT modeling is important at thrust levels greater than $C_t/\sigma = 0.11$ and LRTA modeling becomes increasingly important at thrust levels greater than $C_t/\sigma = 0.09$



Performance Results for Thrust Sweep

- Rotor thrust is predicted within 2.5% for all three modelings
- Propulsive force is slightly under predicted for rotor alone in wind tunnel and is much better predicted with LRTA modeling (prediction-Glauert is not available for this plot set-up)
- Power is slightly over predicted for all three modelings for all thrusts except that prediction of Glauert is under predicted near high thrust limit

Run 45 Series
OVERFLOW2 Performance Results



Conclusions

- 1) Rotor airloads and performance reasonably well predicted with new wind tunnel models and consistent with results obtained from free-air rotor only calculations using a priori angle-of-attack corrections
 - Provides confidence that extension of loosely coupled OVERFLOW/CAMRAD code from free-air to wind tunnel environment was successful
- 2) Speed sweep comparisons
 - Modeling the LRTA and wind tunnel have only limited benefits at low speeds when compared to rotor only calculations using simple angle-of-attack corrections
 - Wind tunnel modeling becomes important at advance ratios greater than $\mu = 0.37$ and LRTA modeling becomes increasingly important as the advance ratio increases

Conclusions - 2

- 3) Thrust sweep comparisons
 - Modeling the LRTA and wind tunnel at high thrust has pronounced effects on the predicted airloads
 - Wind tunnel modeling becomes important at thrust levels greater than $C_t/\sigma = 0.11$ and LRTA modeling becomes increasingly important at thrust levels greater than $C_t/\sigma = 0.09$
- 4) Despite the beneficial effects of modeling the LRTA and wind tunnel, the new models do not completely resolve the current discrepancies between prediction and experiment
- 5) Future work may focus on improving the resolution of the grid systems, including the use of grid adaption algorithms for better wakes capturing